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Quasi-continuum: Lifetimes and feeding to discrete states

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STARS-LIBERACE collaboration

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Outline

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i. Motivation.

ii. What experimental equipment do we have?

iii. How can we utilize our setup to study regions of high level densities?

iv. ^{238}U test experiment.

v. Feeding studies in Mo isotopes using normal kinematics.

vi. Lifetime measurements in the quasi-continuum using inverse kinematics.

vii. Summary.

Motivation

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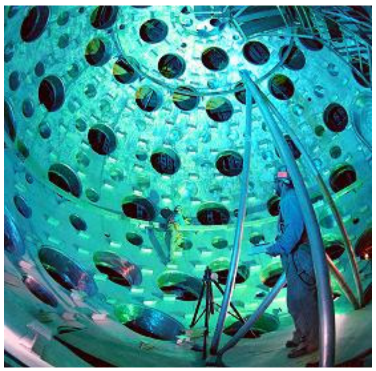
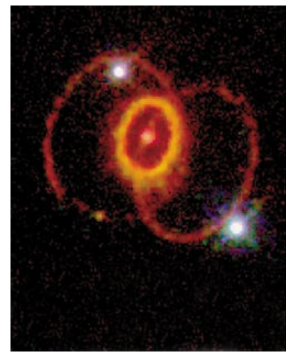
- LLNL's NIF photon flux (~10^{37} photons/cm^2/s) comparable to core-collapse supernovae environment where astrophysical processes take place.



Interior of the NIF target chamber, (30 ft in diameter)



Hubble space telescope image of core-collapse Supernova 1987A, in the Large Magellanic Cloud.

- Photon capture rates in plasma environments may be faster than γ-ray decay of quasi-continuum states → implications for astrophysical processes. See Lee's talk.
- Nuclear level density increases as excitation energy increases → quasi-continuum.
- Not possible to study energy levels individually.
- Average quantities e.g. entropy and γ-ray strength functions describe nuclear properties → Oslo group.
- Developing experimental program to measure lifetimes and characterization of feeding to discrete states

88” Cyclotron at LBNL

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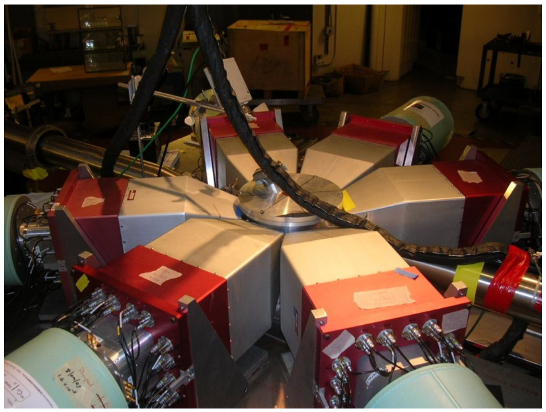
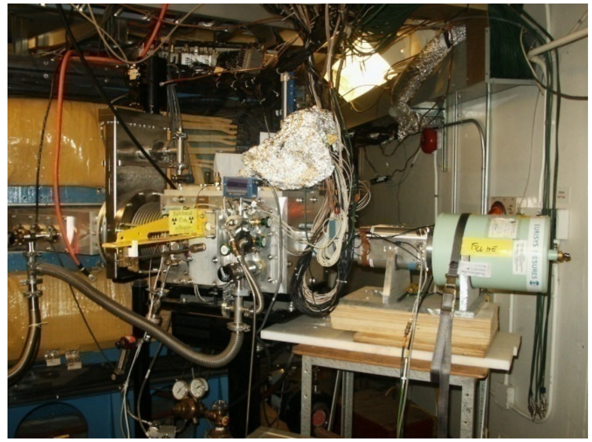
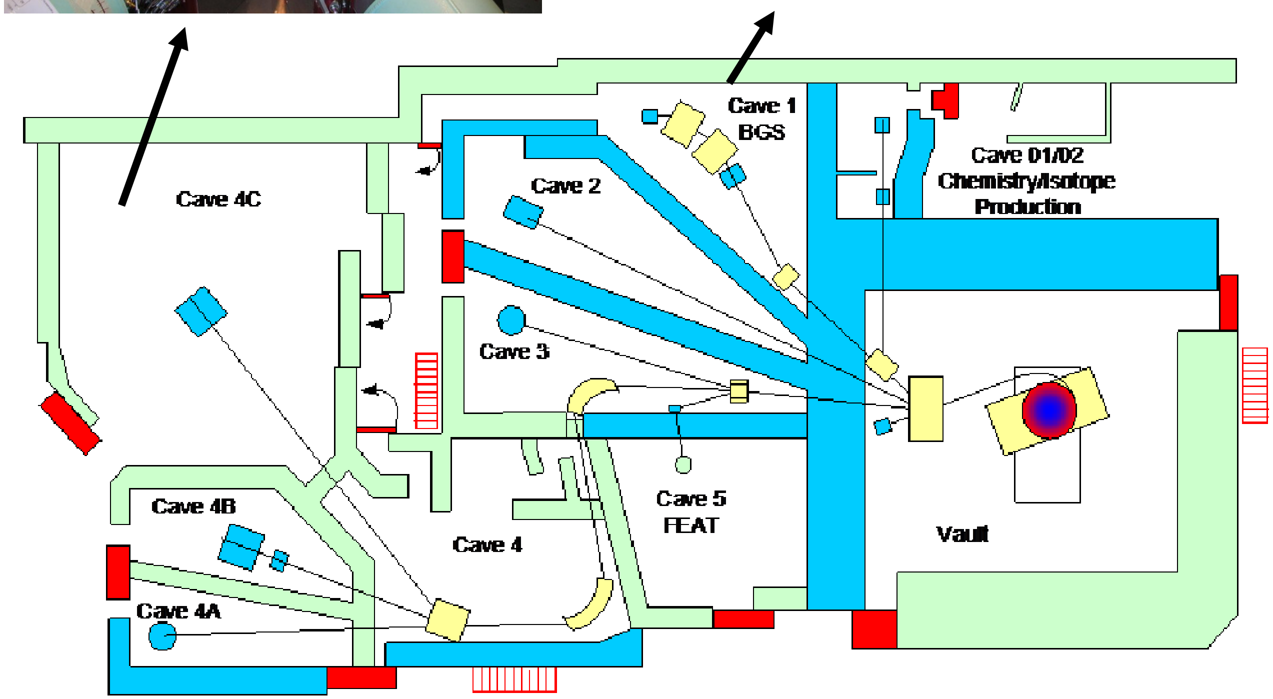
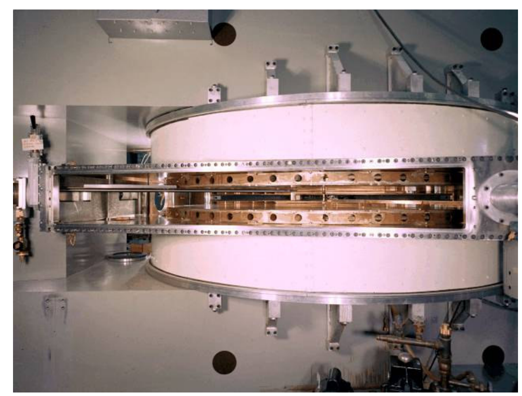






LLNL experiments done in Cave 4C → move equipment to Cave 2 this year.



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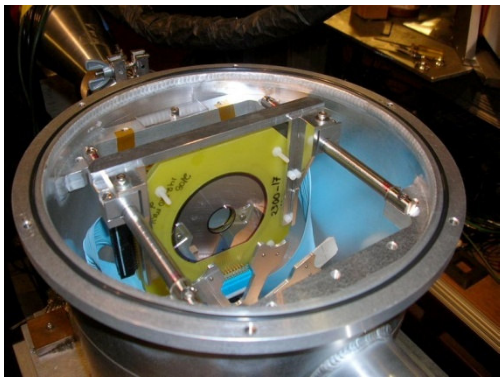
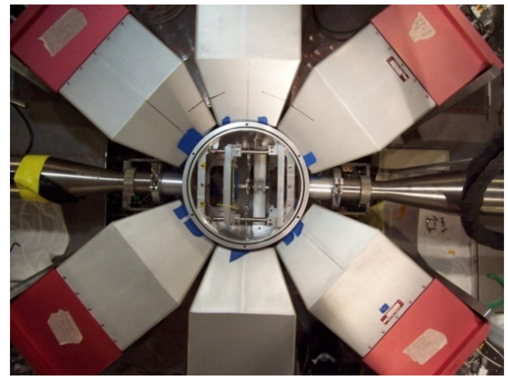
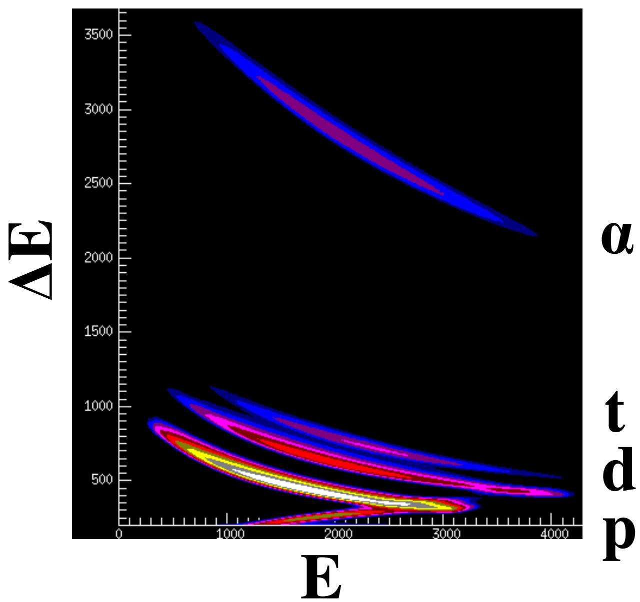
Collaboration between Livermore National Laboratory and Berkeley National Laboratory.



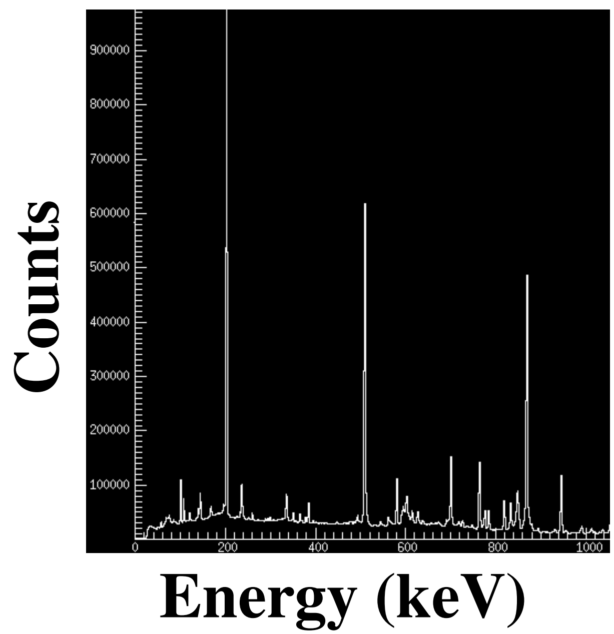
Charged particle detection with large area segmented silicon detectors.



γ-radiation detected with Clover HPGe detectors.



Can build any particle and/or gamma trigger.



Experimental Approach

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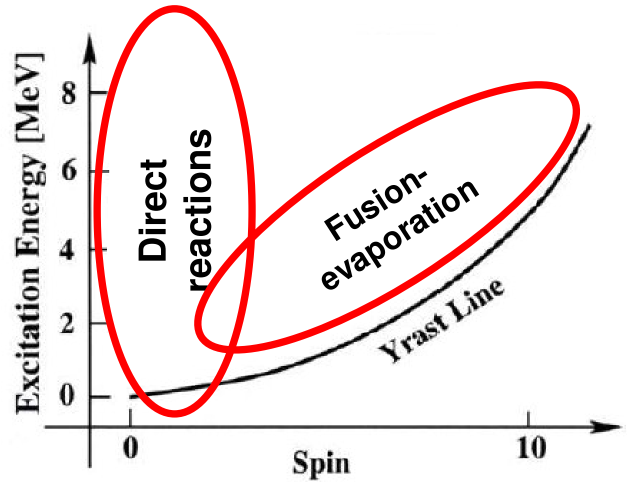
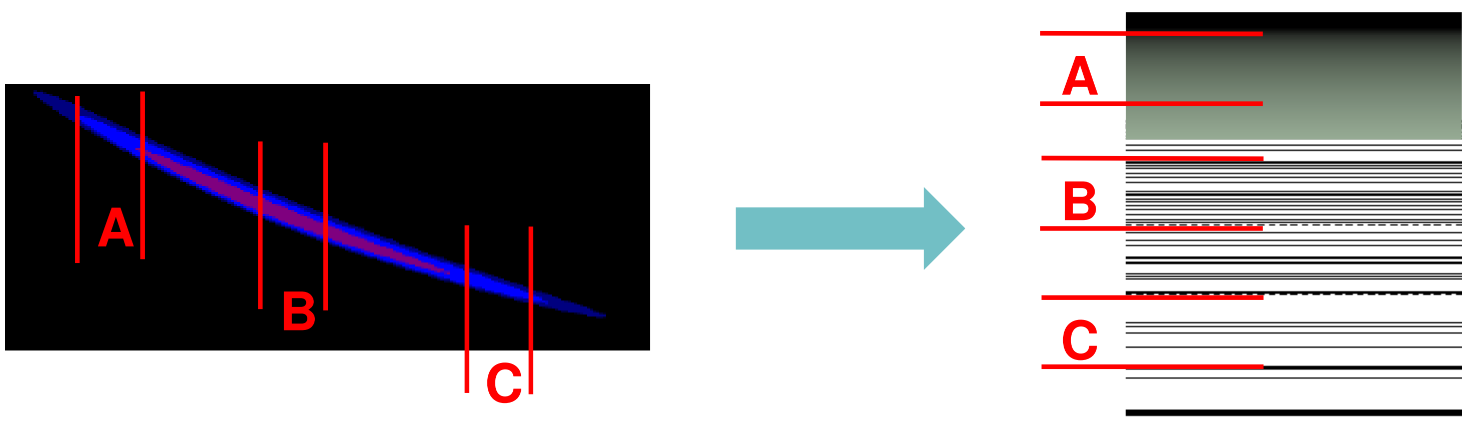
Use direct reactions to populate states with high excitation energy away from yrast line rather than fusion-evaporation which follows along the yrast line.

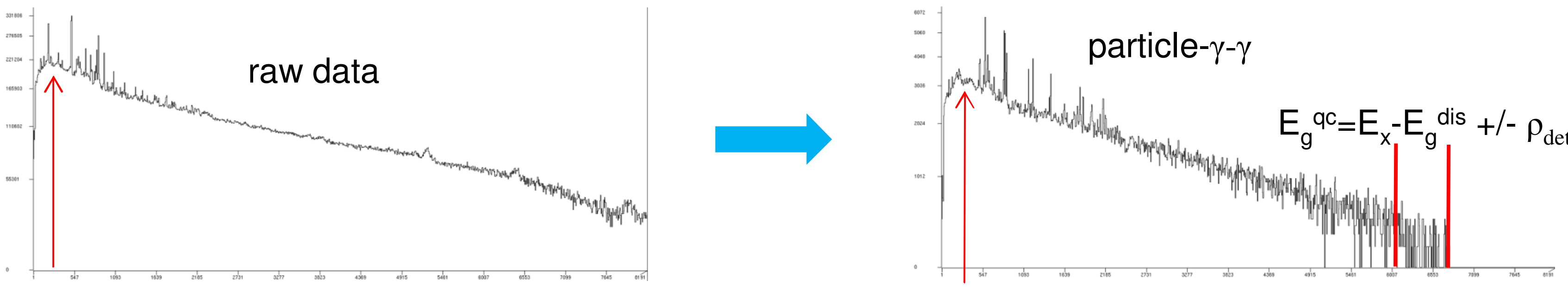


Charged particles will be used to specify entrance excitation energy into the system and γ -rays in coincidence are studied e.g feeding, lifetime.



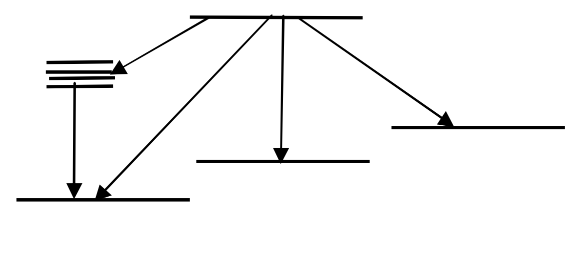
Feeding measurement

- Characterize feeding from continuum.
- Gate on particle energy to establish excitation energy E_x.
- Particle energies are binned and feeding to discrete transitions is analyzed.
- Gate on discrete gamma-ray energy E_g^{dis}
- In p-γ-γ sum of energies $E_g^{qc}=E_x-E_g^{dis} +/- \rho_{det}$ is direct feeding.



- Repeat for different E_x (particle gates) and study feeding.

If excitation energy of discrete states is similar → non-direct feeding same?
Change entrance energy and spin of state (well known) and study dependence of feeding.



Lifetime measurement

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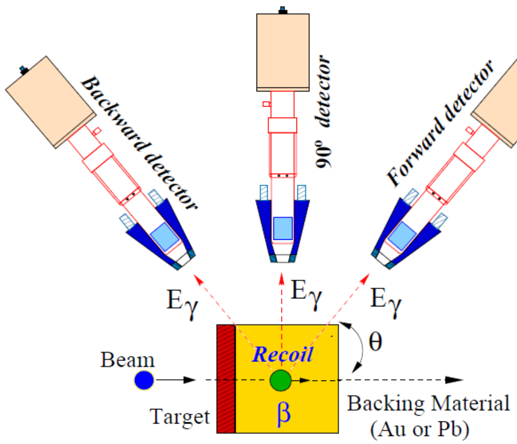
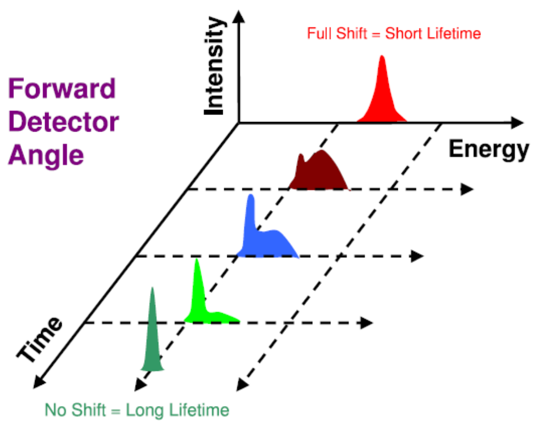
- Particle energies are binned and discrete transitions in coincidence are analyzed.
- Measure Lifetimes from observed Doppler shifts .





- Lifetimes of discrete states are partly dependent on direct and indirect feeding of γ-transitions from levels in the quasi-continuum (need feeding information).
- Differences in the shift in discrete transitions using different particle gates should provide information on the average lifetimes of the gated quasi-continuum region.

Test: $^{238}U(^{16}O,^{16}O^*)^{238}U^*$

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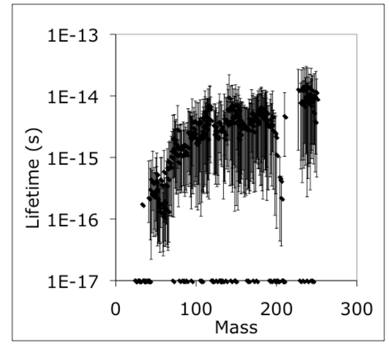
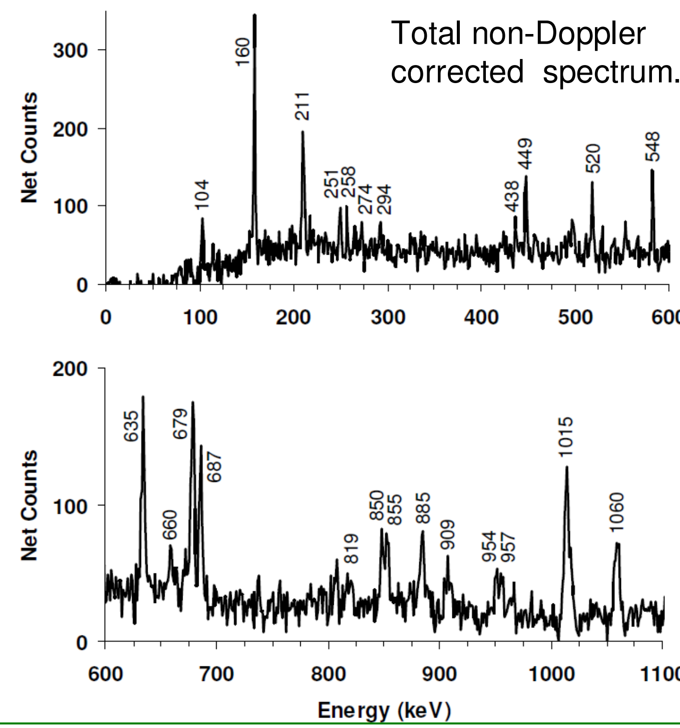
^{238}U target was chosen because of its favorable level structure and longest lifetimes at S_n. 1060 keV 2^+ state with a mean lifetime of 0.92 ps seems like a good candidate.

From neutron capture resonance widths RIPL Obninsk compilation



- Inelastic scattering $^{238}U(^{16}O,^{16}O^*)^{238}U$ at 250 MeV incident on a 1.1 mg/cm^2 thick ^{238}U target with 2 mg/cm^2 Al backing.
- Clover detectors: 140° (2), 90° (2), 40° (1).
- Telescope consisted of a 500 μm ΔE detector and 1000 μm E detector.
- Particle identification can cleanly extracts ^{238}U γ transitions.
- No Doppler shifted components are observed in either transition.



DSAM Model

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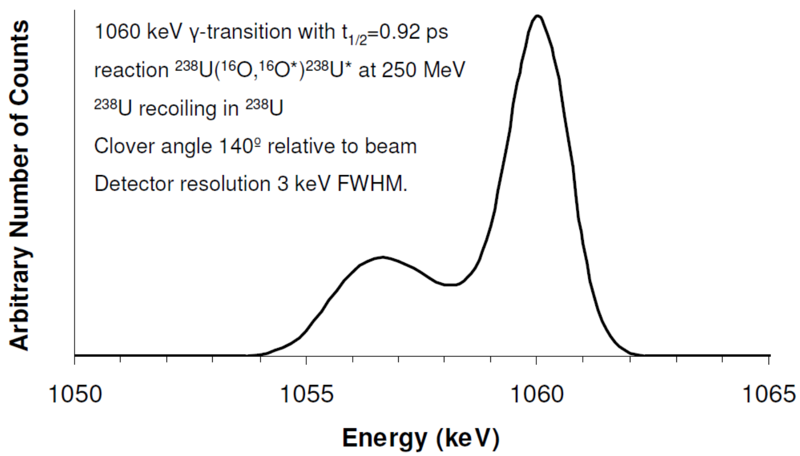

The expected Doppler shifted and stopped components for γ-rays emitted from 1060 keV level. Maximum recoil velocity following the reaction along the beam direction.

- Kinetic energy of the ^{238}U nuclei varies greatly and drops off quickly with ^{16}O detection angle. Immediately after the reaction β=0.0093 at 45˚, β=0.0043 at 20˚.
- Most statistics in the first few degrees of ^{16}O detection where recoil is lowest.
- Most decays occur towards the middle and end of the slowing down process, leaving very little recoil velocity.
- To extract a Doppler shift need much more statistics to gate on large angles.

Lessons learned

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- This work has shown that particle identification can cleanly extracts ^{238}U γ transitions.
- Higher recoil velocities are necessary to obtain well separated stopped and moving components.
- It is highly desirable to perform high statistics experiment to utilize particle-γ-γ coincidence gates → provides unique signals for each transition of interest without possible interference from other decays.
- Lets start with easy beam and target and high cross section reactions to study the feeding from quasi-continuum into discrete states.
- Populate nuclei previously studied by the Oslo group to have a reference point.
- Once feeding is characterized do lifetime measurement.

New Approach

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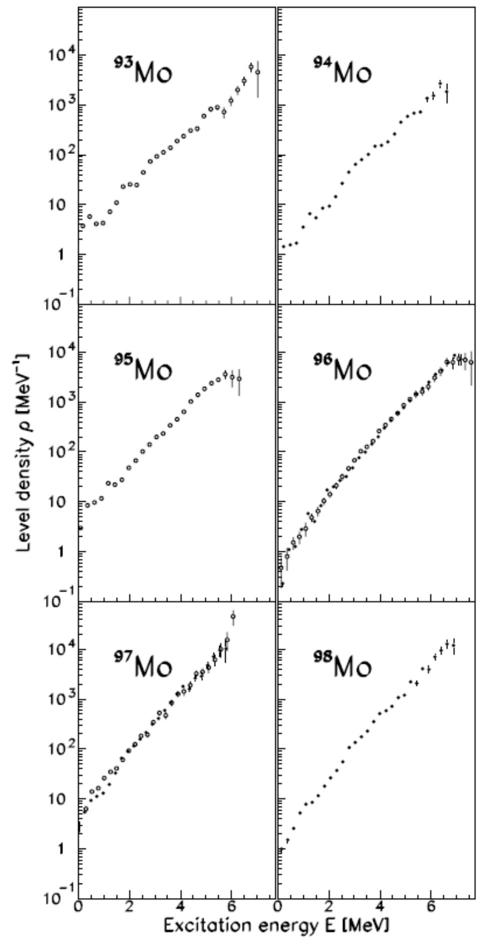
- Measurements are all based on detecting particle to infer the entrance energy.
- Choose Mo isotopes and it has been studied by Oslo:
- Two particle telescopes located up- and downstream.
- Populate Mo nuclei in the transfer reaction Mo(d,p) at 11 MeV beam energy to populate states around S_n with high statistics.
- High resolution γ-ray spectra to study feeding to discrete states.
- The inverse kinematic reaction d(Mo,p) will provide large Doppler shifts.
- Lifetimes longer than ~500 fs use the DSAM.
- Lifetimes shorter than ~500 fs will use the CSM.
- Find states with lifetimes of less than 100 fs to be sensitive to changes in lower fs feeding region.



R. Chankova et al., Phys. Rev. C 73, 034311

Experiment: April 2009

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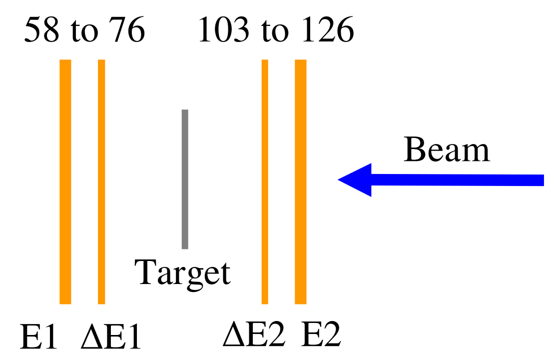
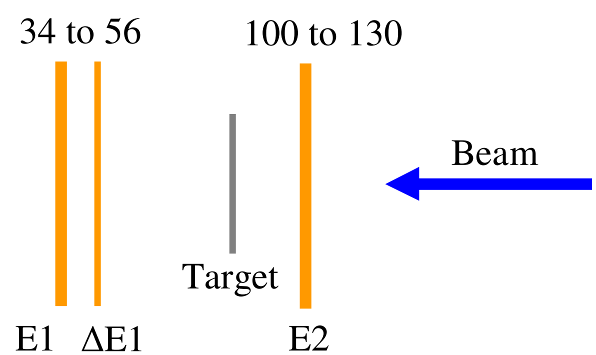
- Establish feeding pattern in normal kinematic reactions: Mo(d,p) at 11 MeV.
- Have thin targets ^{92,93,94}Mo ~200-400 μg/cm^2 → high resolution spectra.
- Use 6 Clovers: 2 each at 140, 90, and 40 degrees.



- Gamma energy range 0-8 MeV for efficiency in high energy region use ^{12}C(d,p) with 3.7 and 3.9 MeV and ^{13}C(d,p) with 6.1 and 6.6 MeV.

- Lifetime in inverse kinematic: d(^{92}Mo,p) 506 MeV.
- Deuteron of 50kV implanted in ^{181}Ta foil (25mg/cm^2).
- ^{93}Mo has a good candidate 1492 keV 3/2$^+$ with a 13.9 (21)fs half life. It decays to the 5/2$^+$ ground state.
- Recoiling nuclei have β~0.11 → ~125 keV shift.



S.D. Pain et al., Nucl. Instr. and Meth. in Phys. Res. B 261 (2007).

Preliminary data (~50%)

^{93}Mo: proton gated γ-rays

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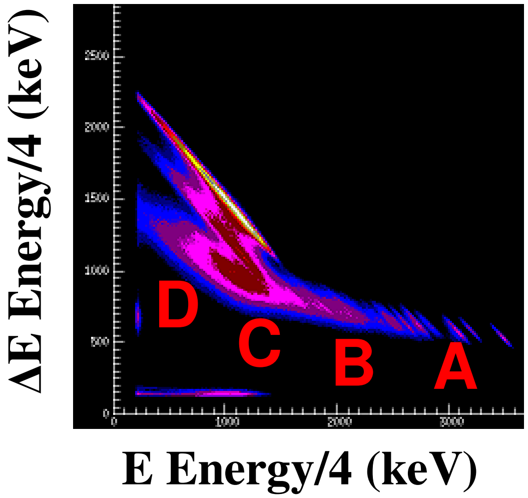
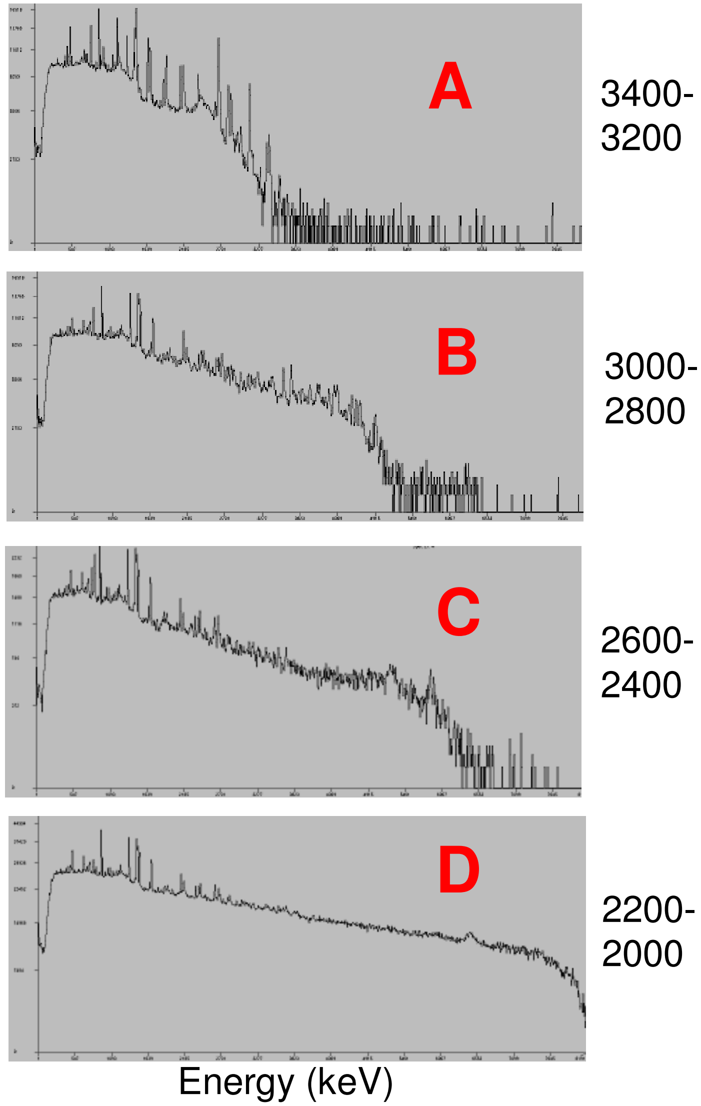
^{92}Mo(d,p)^{93}Mo





For C and D the region of high level density is being populated.
Gating on E_x and a discrete transition the gamma-rays at an energy $E_g^{qc}=E_x-E_g^{dis}$ +/- ρ_{det} are not due to Compton scattering but are due to one step cascades.

Very preliminary

^{93}Mo: γ gated protons

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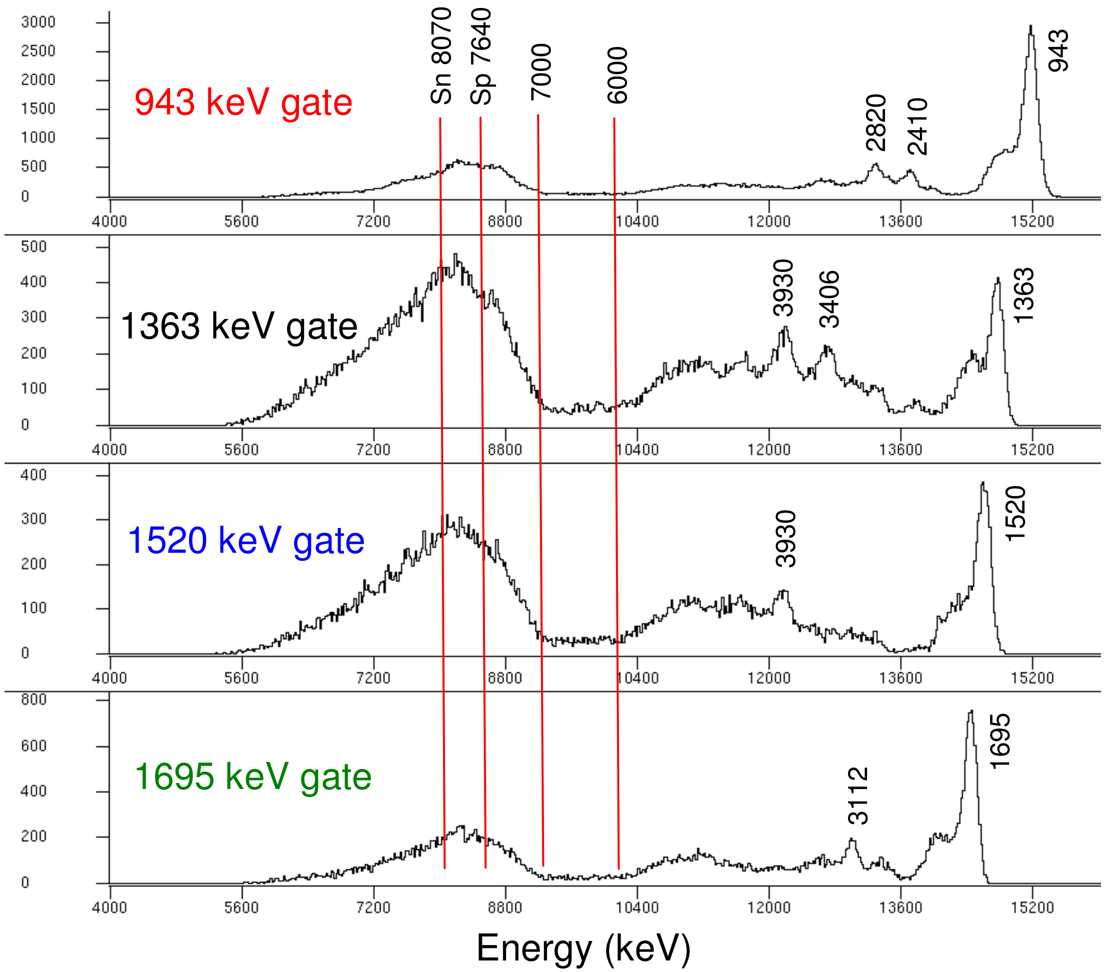

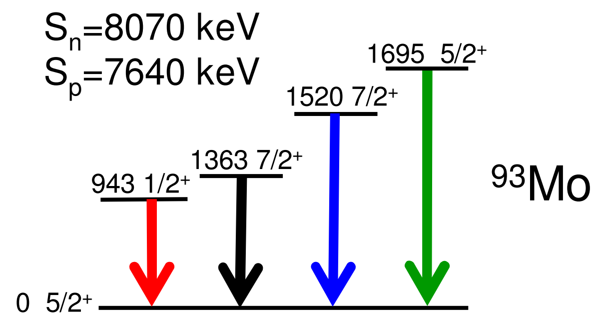

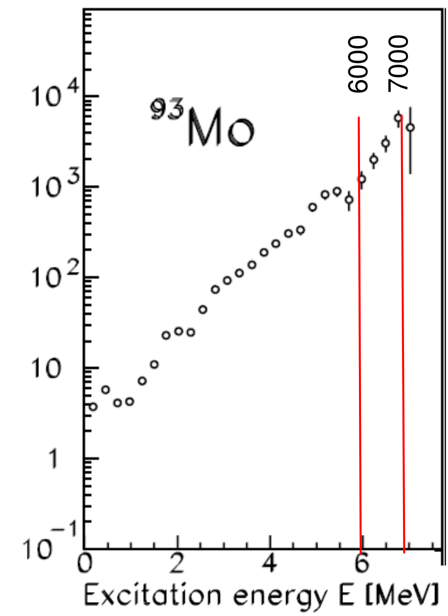

Different in actinides and rare earth nuclei beyond S_n/S_p it drops off quickly.

Very preliminary

R. Chankova et al., Phys. Rev. C 73, 034311

^{95}Mo: p-γ-γ coincidences

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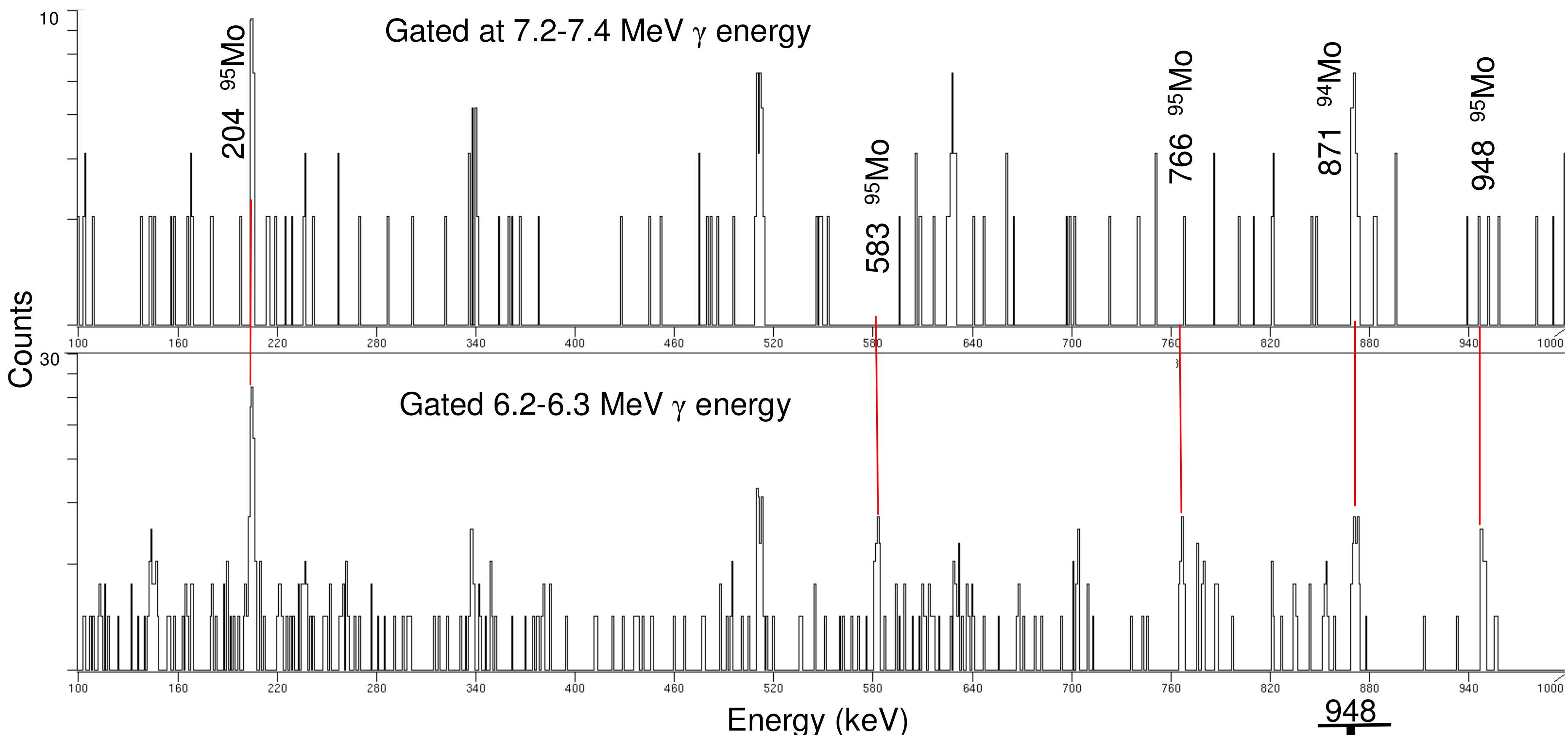
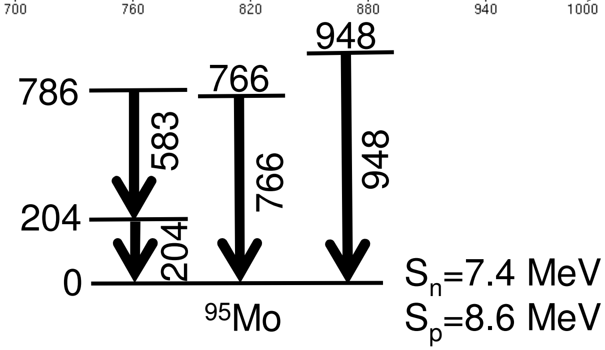


Next step: Use particle energies to change excitation energy.

Very preliminary



Summary and outlook

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- Use STARS-LIBERACE setup to study regions of high-level densities.
- Of particular interests are lifetime measurements in the quasi-continuum and the characterization of the feeding to discrete states.
- Learned from test experiment $^{238}U(^{16}O,^{16}O^*)^{238}U$.
- Production run $^{92,93,94}Mo(d,p)$ to study feeding.
- Analyze data from April 2009 experiment.
- Beam time lead time 2-3 months → if necessary get more statistics.
- Lifetime measurement in inverse kinematics to get lifetime of quasi-continuum.
- We tried ^{92}Mo beam on deuteron implanted in ^{181}Ta foil.
- It appears there were no deuterons in the Ta foil.
- Need a better D target allowing for lifetime measurement (chemical bond).
- Possibility to run a lifetime measurement experiment this fall.

Thank you!

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